Long Range Acoustic Communication in Deep Water

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LONG TERM GOALS

Develop and experimentally confirm robust self-adaptive algorithms for coherent communications between a source and a towed array at very long ranges in deep water.

OBJECTIVE

Experimentally confirm that robust coherent acoustic communication is feasible between a source and receiving array at speed and depth at long ranges in deep water with separations as much as 2000 km.

APPROACH

Acoustic communication at long range in the ocean is challenging due to the substantial propagation loss, multipath delay spread, and channel variability. Analysis of deep-water data collected as part of the ONR Acoustic Thermometry of Ocean Climate (ATOC) program has suggested that coherent acoustic communications is feasible at long ranges [1,2]. By treating the tomography signals (m-sequence transmissions) as BPSK communication signals, successful recovery of the sequence of bits has been demonstrated. One example is from the ATOC Acoustic Engineering Test (AET) in November 1994 where 1023-digit m-sequences were transmitted at a 75 Hz center frequency to a 20-element (700 m aperture) vertical array at approximately 3250 km range in the NE Pacific Ocean [1]. An information rate of 37.5 bits/s was achieved.

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Recently, Shimura et al. carried out a long-range acoustic communication experiment in deep water, south of Japan. In this case, the source and vertical receive array were moored ~600 km apart in the vicinity of the sound axis (~1000 m depth). Using a source level of ~196 dB and 16 QAM modulation over the higher frequency band (450-550 Hz), a data rate of 400 bits/s was achieved [3]. Multiuser or MIMO (multiple-input/multiple-output) communications also was demonstrated for up to three users at ranges of 500-600 km, achieving a few hundred bits/s for each user [4].

In September 2010 a long-range acoustic communication (LRAC10) experiment was carried out in deep water off the Southern California Coast. In contrast with previous communications/tomography experiments where the source and receiver typically are moored at around the sound channel axis (e.g., 1000 m), the LRAC10 experiment involved a shallow source (J15-3) at 75-m depth and a horizontal line array (FORA [5]) towed at 3.5 knots at 200-m depth at various ranges (100-700 km) [6]. Due to the modest source level (~172 dB), beamforming of the received signal was crucial to providing adequate SNR for acoustic communication. Using QPSK modulation over the band of 200-300 Hz, a data rate of 50-100 bits/s at ~550 km range was achieved [7,8]. To enhance the SNR and improve the performance, various diversities such as beam diversity [8] and spatial/temporal diversity [9] were exploited. In addition, a robust algorithm (double differentially coded spread spectrum) was demonstrated recently using the LRAC10 data [10].

WORK COMPLETED

Based on the promising results from the long-range acoustic communication 2010 (LRAC10) experiment carried out in deep water off the Southern California Coast. The original plan was to conduct an experiment in February 2014 (LRAC14) in the Philippine Sea involving: (1) NRL-SSC Helmholtz resonator source (200-1000 Hz) that is part of DTAGS (Deep Towed Acoustic Geophysics System) and (2) The FORA (Five Octave Research Array) operated by ARL/PSU. LRAC14 aimed to demonstrate experimentally robust self-adaptive algorithms for coherent communications between a source and a towed horizontal array in deep water at very long ranges (~2,000 km). Unfortunately, a potentially serious problem with the FORA array was found prior to shipping and the LRAC14 experiment was cancelled at the last minute.

Instead we explored the possibility of using gliders equipped with a single hydrophone for long-range acoustic communication in deep water. The primary use of underwater gliders is to collect oceanographic data within the water column (e.g., temperature and salinity) and transmit their data to shore periodically downloading instructions at the surface via a satellite connection. However, the mission of gliders has expanded into acoustics lately [11-13]. For example, [7] reported successful deployment of Spray gliders with a commercial acoustic modem for data retrieval from subsurface moorings and seafloor systems installed with a similar modem in deep water [11]. Several tests of acoustic communications between gliders and between gliders and other platforms have taken place at few km ranges in shallow water [12]. More recently, GPS-based surface positions have been combined with subsurface position estimates in the Philippine Sea derived from acoustic signals transmitted for the purpose of performing acoustic tomography [13].

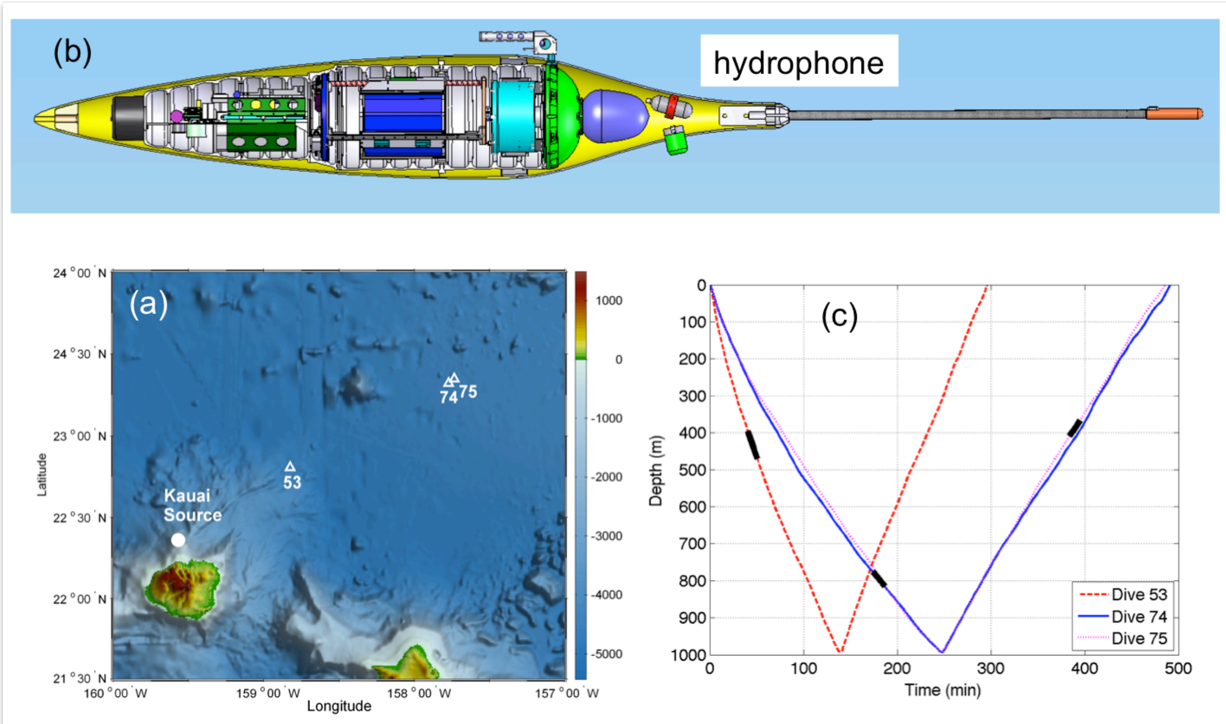

Figure 1. (a) The Kauai source (filled dot) is bottom-mounted off Kauai, Hawaii. Triangles indicate GPS positions of the glider at the beginning of each dive at the surface. (b) The acoustic Seaglider. The hydrophone is in the tail cone at the top. (c) Glider positions at the time of receptions (highlighted segments) superimposed on the profile of Dives 53, 74, and 75. Note that Dive 75 is almost identical to Dive 74.

In summer 2006, a Seaglider equipped with an acoustic recording system (ARS) received transmissions from a broadband acoustic source centered at 75 Hz deployed on the bottom off Kauai, Hawaii, while moving away from the source at ranges up to ~200 km in deep water and diving up to 1000-m depth (see Fig. 1). The transmitted signal was an m-sequence that can be treated as a BPSK communication signal as in the ATOC/AET experiment which exploited either (a) spatial diversity provided by a vertical array or (b) temporal diversity provided by the time-varying ocean itself with a single stationary receiver. On the other hand, the gliders are in constant motion diving to depths of ~1000 m and traveling horizontally at about 0.25 m/s (half a knot) for several hours during a dive, naturally inducing a combination of spatial and temporal diversity that can be utilized for acoustic communication [14]. Previously, similar spatial/temporal diversity was investigated for synthetic aperture communications (SAC) [2] exploiting the relative motion between a source and receiver where the moving source was confined to only horizontal motion (i.e., constant depth).

We focus on three receptions captured during Dives 53, 74, and 75 at approximate source-to-glider ranges of 100 km and 200 km, respectively, as marked in Fig. 1(a). The glider profile is illustrated in Fig. 1(c) where highlighted segments indicate glider positions at the times of source signal reception: 450 m, 800 m, and 400 m, respectively. Note that the profiles of Dives 74 and

75 are almost identical. The performance of BPSK communications for individual receptions (Dives 53 and 74) is shown in Fig. 2 as a scatter plot. The output SNR is 5 dB for both cases with a bit error rate of about 2%. The output SNR is comparable to the input SNR. Although not shown, Dive 75 yields the worst performance with an output SNR of 3.5 dB due to its lower input SNR. The two receptions (Dives 53 and 74) can be combined coherently. The performance enhancement due to diversity combining is clearly evident in Fig. 2 (rightmost) with an output SNR of 8 dB, achieving a 3-dB increase from individual cases (5-dB). Further combining all three receptions (Dives 53, 74, and 75) leads to an error-free performance with a 9 dB output SNR.

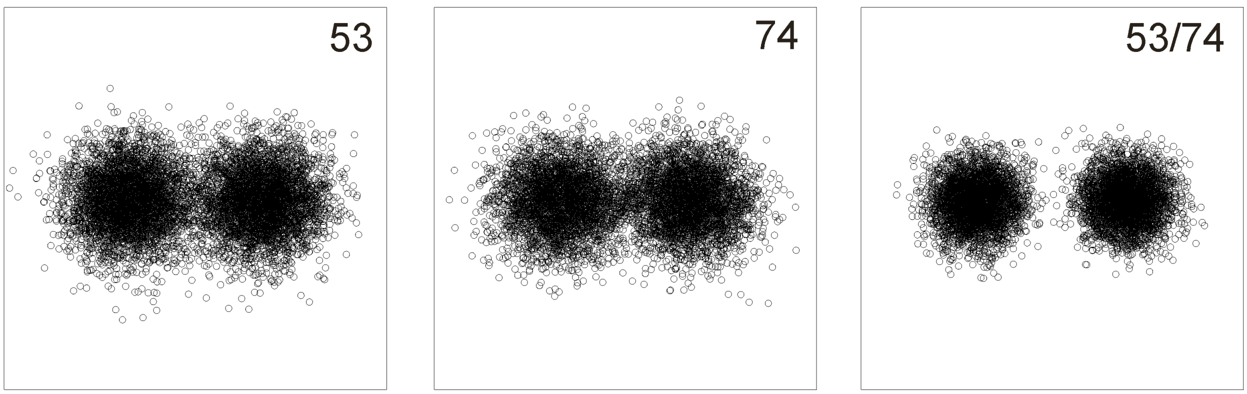

Figure 2. Performance of BPSK communications for two individual receptions during Dives 53 and 74 (left two panels). The output SNR is about 5 dB for both cases with a bit error rate of 2%. The performance enhancement due to diversity combining (53 and 74) is evident in the rightmost panel with an output SNR of 8 dB. A TR-DFE with MP is employed for multichannel equalization.

IMPACT/APPLICATIONS

The feasibility of using a glider for long-range acoustic communications has been demonstrated in deep water by combining multiple receptions during each dive. The implication is that the gliders can operate as mobile gateways (i.e., base stations) to relay messages from submarines at speed and depth within a cell or coverage range (e.g., 500 km) to shore via a satellite connection.

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